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U.S. Air Force Aircrew Flight Protective Eyewear Program

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This publication recommends optimal design and material factors for consideration in the development of flight protective eyewear (FPE). FPE provides protection from dust, flying debris, and ballistic hazards. This publication highlights those state-of-the-art features that should serve as the existing standard model in the development of FPE. In general, FPE should provide the maximum possible field of view and be lightweight, comfortable, and compatible with existing aircrew equipment assemblies while avoiding harm during accidents. Included in this report is design guidance relating to FPE, the FPE List, and a report of findings from the Aircrew Ballistic Protective Eyewear Study II.

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TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

The aim of this publication is to recommend optimal design and material factors for consideration in the development of flight protective eyewear (FPE). FPE provides protection from dust, flying debris, and ballistic hazards. This publication will highlight those state-of-the-art features that should serve as the existing standard model in the development of FPE. In general, FPE should provide the maximum possible field of view and be lightweight, comfortable, and compatible with existing aircrew equipment assemblies while avoiding harm during accidents.

Design guidance relating to FPE can be found in Appendix A. The FPE List (FPEL) is in Appendix B. A report of findings from the Aircrew Ballistic Protective Eyewear Study II can be found in Appendix C.

2.0 MATERIALS

2.1 Frames

2.1.1 General. All FPE frames should be constructed of corrosion-resistant, strong, light, durable, hypoallergenic, and nationally approved materials that will not degrade with environmental extremes or chemical contamination. All joints and screws must be treated to ensure their integrity under stress including impact. The fronts and eye shape are to be designed for maximum field of view and compatibility with aircrew protective helmets and oxygen masks, and adequate provision for air circulation to minimize misting must be allowed; style and cost should be of secondary importance. The sides should be slim to avoid discomfort from close-fitting helmets and designed to allow easy donning and doffing in flight and to minimize any distortion of ear seals with a consequent loss of sound attenuation. The frame should not deform in use and should be free of projections, sharp edges, or other features that could impair comfort. The frame should be treated to minimize reflections. The frame/lens combination shall be nonflammable.

2.1.2 Bridge/Temple. Malleability to facilitate facial contouring and integration with personal flying equipment is desirable in any frame formulation.

2.1.3 Eyewire. Material selected should be strong and capable of being manufactured into existing safety standards. The potential for rearward displacement of the lens element following impact must be minimized. Material selected should ensure positional stability of the lens elements.

2.2 Lenses

2.2.1 Quality. All lenses should be fabricated from material of high optical quality that is also robust, lightweight and, whenever possible, of low flammability and stable to ultraviolet (UV) radiation. Lenses should not demonstrate any defects of material such as blisters, streaks, inclusions, pits, ripples, or other defects that would impair vision under normal conditions of use.

2.2.2 Critical Visual Area. All optical and material requirements of this agreement, unless otherwise specified, shall refer to the "Critical Visual Area," which shall be that part of the lenses included in the total field of view obtainable under all conditions of use.

3.0 BALLISTIC AND IMPACT RESISTANCE: BALLISTIC FRAGMENTATION OF FPE

All FPE should meet the minimum ballistic requirements of the Army Military Combat Eye Protection (MCEP) standards. National standards may be substituted where these test to a similar or higher performance. The ballistic test of FPE devices involves mounting the eyewear on a European Norm (EN) headform in the as-worn position and impacting the device with fragment-simulating projectiles of specified shape and dimension. The test is considered a failure if any of the following occur: the aluminum foil witness sheet (adhered to the EN headform) is perforated, the primary lens is cracked (defined as a break that propagates from one surface of the lens to the other), one or more fragments become dislodged on the inside of the primary shield to include coatings, eyewear components become completely separated from the frame upon impact, or the eyewear falls off the headform.

3.1 Ballistic Tests of FPE Spectacles

The test for FPE spectacles involves striking the mounted FPE device once with a 0.15-caliber, 5.85±0.15-grain, T37-shaped projectile at 640 to 660 ft/s at normal incidence (zero degree obliquity) to the primary lens at a location within the critical area. The critical area is defined as a circle having a 20-mm radius centered on the horizontal centerline and 32 mm from the vertical centerline.

3.2 Ballistic Tests of FPE Goggles

The test for FPE goggles involves striking the mounted FPE device three times with a 0.22-caliber, 17±0.5-grain, T37-shaped projectile at 550 to 560 ft/s, once on the left side and once on the right with both impacts at normal incidence (zero degree obliquity) to the primary lens at a location within the critical area. The third shot shall be in the center at the vertical centerline at normal incidence (zero degree obliquity) to the primary lens. The critical area is defined as a circle having a 20-mm radius centered on the horizontal centerline and 32 mm from the vertical centerline.

4.0 FITTING OF PERSONAL FLYING EQUIPMENT

It is essential that aircrew have their eyewear devices properly fitted. This is especially important as it relates to integration with helmet, oxygen mask, night vision goggles (NVG), and other flying equipment. It is therefore recommended that aviators have their helmets, NVG, oxygen masks, and/or headphones available during any eyewear fitting session. This will facilitate any adjustments before and after the prescription is fabricated and maximize the integration of the flyer's eyewear devices with his/her personal equipment under the best possible conditions to reach the optimal compromise of comfort, optical correction, and function.

APPENDIX A

Design Considerations for Flight Protective Eyewear

FRAMES

FPE Spectacles

Spectacles should protect the eyes of aircrew from hazards/threats associated with ballistic (fragmentation) and electromagnetic radiation, including bright sunlight and harmful UV radiation. Additional wind/dust protection in the form of a seal around the eye socket is optional. Spectacles should be compatible with the Universal Prescription Lens Carrier (UPLC). Primary means of retention for spectacles shall be temple arms; however, an additional retention strap shall be included for use in conjunction with, or in place of, the temple arms. Size must meet the 5^{th} percentile female through the 95th percentile male design critical dimensions as referenced in the MCEP.

FPE Goggles

Goggles should protect the eyes of aircrew from hazards/threats associated with ballistic (fragmentation) and electromagnetic radiation, including bright sunlight and harmful UV radiation. Goggles shall provide a protective seal around the eyes to protect from wind/dust. Goggles should be compatible with the UPLC. Primary means of retention for the goggles shall be a goggle strap. A protective sleeve shall be provided for the goggles when not in use. Size must meet the 5^{th} percentile female through the 95th percentile male design critical dimensions as referenced in the MCEP.

Color

Frames shall be available in Black 357, Tan 499, and Foliage Green 504. The finished eyewear shall match the standard sample for shade and appearance. Retention straps and protective sleeves shall match the eyewear frame in solid color. Carrying cases shall match the eyewear frame in solid color. Findings (thread, zippers, webbing, snaphooks, etc.) shall be a reasonable match to the carrying case. Matte finishes are recommended.

CARRYING CASE

Carrying case shall be provided for eyewear. The carrying case shall be capable of carrying one FPE system (eyewear, retaining strap, instruction booklet, cleaning cloth, and anti-fog reapplication) with or without attached prescription lenses and at least one extra protective lens. The carrying case shall be designed to allow for quick and easy access to the FPE system by the user and shall be operable and resistant to breaks, cracks, discoloration, corrosion, and rust during operation, shipping, and storage. The carrying case should be able to fit in the aircrew member's clothing pockets.

INSTRUCTION BOOKLET

An instructional booklet shall be provided that, at a minimum, includes a description and use of the FPE system including applicable UPLC insertion/removal instructions and diagrams, configurations, and maintenance and cleaning procedures. Information related to safety shall also be included, as appropriate, and shall be made to stand out from the remainder of the text. Language shall be simple, clear, and concise. Type style, size, and spacing shall be in accordance with best commercial practices for technical publications. The instruction booklet shall be small enough to enable packing in the FPE system carrying case, yet the print shall be large enough to be read by the individual.

COMPONENT CHANGES

Component changes such as installation/removal of protective lenses, retention straps, nose pieces, frames, and UPLC shall not require the use of tools and shall be able to be accomplished during day and night conditions.

UNIFORMITY IN SYSTEM DIMENSIONS

The FPE system end item components (i.e., lenses, frames, nose pieces, prescription lens carriers, straps, and associated attachment mechanisms) shall be uniform in dimension between items of the same class, size, and product. The lenses, frames, nose pieces, UPLC, straps, and attachment mechanisms shall be able to be changed out from one item of the same product line and used on another item of the same product line with no degradation of capabilities.

SYSTEM WEIGHT

The weight of the FPE spectacles, including the applicable UPLC, shall not exceed 48.2 grams (1.7 ounces). The weight of the empty carrying case for the spectacles shall not exceed 141.75 grams (5 ounces). The weight of the FPE goggles, including the applicable UPLC, shall not exceed 144.58 grams (5.1 ounces). The weight of the empty carrying case for the goggles shall not exceed 226.80 grams (8 ounces).

INTERFACE REQUIREMENTS

The FPE system will functionally and comfortably integrate when being used with current weapons; clothing; and equipment normally carried, worn, or used by aircrew, such as helmets, oxygen masks, visor/mandible cover, communication gear/headset, heads up display, NVG, quick don masks, firefighter smoke mask, and other flight equipment.

PRESCRIPTION LENSES

Spectacles and goggles shall be able to accommodate the use of the UPLC filled with polycarbonate ranging from +8.00 to -8.00 diopters without degrading ballistic and vision performance. The UPLC, when used with FPE, must be stable and unaffected by vibrations that affect optical quality. FPE that does not accommodate the UPLC may be worn by aircrew members who do not require vision corrective lenses.

MATERIALS/CHARACTERISTICS

Use of recycled, recovered, or environmentally preferable materials is encouraged when practical, provided the performance requirements are met. The materials used in the eyewear shall be resistant to mildew. The eyewear lenses shall maximize chemical resistance to 6.0% sodium hypochlorite by weight, N,N-diethyl-meta-toluamide, all colors of camouflage face paint with insect repellent (MIL-DTL-32000), fire-resistant hydraulic fluid (MIL-PRF-46170), petroleum-based hydraulic fluid (MIL-PRF-6083), gasoline (87% octane), motor oil (Quaker State Peak Performance, SAE 10W-30), and JP8 fuel (MIL-DTL-83133E). FPE shall be able to withstand, at a minimum, 24-hour exposure to the chemicals (listed) without having degradation of optical or ballistic fragmentation performance. Both clear and tinted lenses shall be included as part of all testing.

BALLISTIC FRAGMENTATION CHARACTERISTICS

FPE Spectacles

Spectacles shall provide ballistic fragmentation protection in all configurations. Spectacles shall be sufficiently durable to remain intact (i.e., all components required for protection and proper retention of the eyewear remain attached) upon/after impact. Spectacles shall be tested with and without prescription lenses for initial approval of the design for use with the UPLC. Adaptors that are used to make the spectacles compatible with the UPLC shall be able to survive a ballistic fragmentation impact in all configurations for which they are intended. The assembly and associated interfaces shall be sufficiently durable to remain intact upon impact.

FPE Goggles

Goggles shall provide ballistic fragmentation in all configurations. Goggles shall be sufficiently durable to remain intact (i.e., all components required for protection and proper retention of the eyewear remain attached) upon/after impact. Goggles shall be tested both with and without prescription lenses for initial approval of the design for use with the UPLC. Adaptors that are used to make the goggles compatible with the UPLC shall be able to survive a ballistic fragmentation impact in all configurations for which they are intended. The assembly and associated interfaces shall be sufficiently durable to remain intact upon impact.

OPTICAL CHARACTERISTICS

Eyewear shall be capable of meeting the optical requirements with and without the UPLC installed (including the use of multiple nose pieces to accommodate both prescription and nonprescription wearers). All eyewear must be able to pass all optical requirements within the critical optical area. The critical area is defined as a circle having a 20-mm radius centered on the horizontal centerline and 32 mm from the vertical centerline.

LUMINOUS TRANSMITTANCE AND NEUTRALITY

Clear Lens

If multiple lenses are used to provide ballistic fragmentation and sun/UV protection, the photopic luminous transmittance (for the light-adapted eye) of the lens shall not be less than 89%. The ratio, R, of the two measured transmittances between right to left areas on the same system shall be between 0.90 and 1.10 ($0.90 \leq R \leq 1.10$) when measured at similar points within the critical optical area.

Tinted Lens (Sunglasses)

If multiple lenses are used to provide ballistic fragmentation and sun/UV protection, the photopic luminous transmittance shall be within 12% to 18% when measured within the critical optical areas. The ratio, R, of the two measured transmittances between right to left areas on the same system shall be between 0.90 and 1.10 ($0.90 \leq R \leq 1.10$) when measured at similar points within the critical optical area.

Neutrality

The spectral transmittance of the tinted (sunglass) lens may vary with wavelengths between 430 and 730 nm; the average percentage deviation within nine spectral bands shall be less than 12%. The spectral distribution curve shall show a reasonably even distribution throughout the visible spectrum to ensure that color distortion will not be excessive.

FIELD OF VIEW

FPE spectacles and goggles shall provide unobscured vision with a field of view adequate for mission with and without the UPLC installed.

ABRASION

FPE spectacles and goggles shall maximize resistance to scratching/abrasion to minimize interference with vision. Initial haze of the eyewear shall conform to American National Standards Institute (ANSI) Z87.1. No more than 6% haze shall be added to the baseline haze value as a result of abrasion testing.

FOGGING

FPE spectacles and goggles shall maximize resistance to fogging to minimize interference with vision. The device shall not fog to the extent that the user is unable to perform his/her intended mission.

PRISMATIC POWER

Prismatic power requirements for the eyewear shall be in accordance with ANSI Z87.1.

OPTICAL DISTORTION

Lens shall be free of blurs or distortion (evidenced by waves or ripples or shearing patterns) in the image of a straight line in any meridian when viewed through the lens.

ULTRAVIOLET ABSORPTION

Lenses shall absorb at least 99.9% of the incident UV radiation in the range of 290 to 380 nm.

SERVICE LIFE/SHELF LIFE

FPE spectacles and goggles shall have a minimum field life of 6 months and a minimum shelf life of 60 months or longer. The eyewear shall be capable of being repaired by replacing components that have become damaged. Repairs shall be capable of being performed without tools.

ENVIRONMENT

FPE spectacles and goggles shall be capable of being worn/used in all climatic categories (i.e., -60 °F to 120 °F) during day, dusk, and nighttime operations and during various environmental conditions, such as rain, snow, wind, etc. The eyewear shall be capable of being exposed to solar radiation and water without degrading eyewear capabilities.

COATING

If coating has been applied to the lens, the coating on the front and back surface of the lens shall not be able to be removed, dislodged, or affected in any way.

PANTASCOPIC TILTS AND FACEFORM ANGLES

The UPLC when used with the spectacles or goggles shall not have a pantascopic tilt greater than 15% or less than 0 degrees and shall not have a faceform angle greater than 24 degrees (12 degrees per lens).

COMFORT

FPE spectacles and goggles shall be designed to minimize localized discomfort (hot spots) and eyelash contact. There shall be a means to adjust the eyewear for proper fit and comfort. The finished parts of the eyewear shall be free of sharp/rough edges, which could result in discomfort or abrasion to the face.

DONNING/DOFFING

FPE spectacles and goggles shall be easily and quickly (less than 10 seconds) donned and doffed with minimal realigning and readjusting. Donning/doffing of the spectacles shall be without the retention strap, since its use is optional, and shall be to/from the carrying case. Donning/doffing of the eyewear in general shall be accomplished without removing other equipment.

COMPLIANCE WITH ANSI Z87.1

FPE goggles and spectacles (with and without the UPLC) shall be fully compliant with the current edition of ANSI Z87.1. The eyewear shall be assessed as a high impact protector. The eyewear shall meet impact protection requirements in all configurations (including the use of multiple nose pieces to accommodate both prescription and nonprescription wearers). Peripheral protection shall likewise be demonstrated in all configurations. Both clear and tinted (sunglass) assemblies shall be tested.

FLAMMABILITY

Flammability for the eyewear shall be in accordance with ANSI Z87.1-2003 and ANSI Z87.1-2010. This shall include any plastic components such as buckles, retention straps, etc. that are on FPE spectacles and goggles. Textile components (not covered by ANSI Z87.1), including the retention strap and protective sleeve, shall be flame resistant. Five samples of each textile component shall be exposed to a vertical flame when tested, shall not exhibit a char length greater than 10 cm, and shall not exhibit any visible afterglow for greater than 20.0 seconds average after removal from test flame. Textile components shall not exhibit flaming melt-drip. Cleaning cloths and carrying cases are exempt from this requirement.

TEST SAMPLE SIZE

ANSI testing shall be conducted, at a minimum, on sample sizes as specified in the current version of ANSI Z87.1 for each configuration tested. Where no specific sample size is given in ANSI Z87.1, a minimum of three samples shall be used, with the exception of ballistic fragmentation testing, where a minimum of 10 samples shall be used. Post-exposure ballistic fragmentation testing (such as post-chemical) shall be conducted on a minimum of three samples of the exposed device.

USER EVALUATION

As part of the qualification requirement, the eyewear will be subjected to a field user evaluation. Aircrew shall wear the eyewear while performing training, flight duties, and other duty-related tasks. Field testing of spectacles and goggles shall include an assessment of fit, comfort, stability, compatibility with equipment, perception of weight when worn, appearance, clarity of vision, field of view, ease of changing lenses, ease of fit and adjustment, durability, resistance to fogging and scratching, appearance of device, UPLC compatibility, and level of protection from dust and debris. Upon completion of the user evaluation, the users will score the eyewear on each requirement and the scores will be on a scale of “1” (worst/very poor) to “5” (best/very good).

APPENDIX B

Flight Protective Eyewear List

ESS Suppressor (spectacles)

Revision Sawfly (spectacles)

Wiley-X Talon (spectacles)

Oakley SI Ballistic M Frame 2.0 (spectacles)

Revision Exoshield (goggles)

Revision Bullet Ant (goggles)

***Wiley CQC—removed from the FPEL January 2013 based on findings from Aircrew Ballistic Protective Eyewear (BPE) Study II (Annex C)

Flight Protective Eyewear	Recommended Usage (Based on BPE Study II)
ESS Suppressor	Thin temples are compatible with communication headgear; high degree of fog resistance; high compatibility/comfort with flight equipment; provides limited dust/debris protection; found compatible with 55P, 56P, FAST helmets by various aircrew positions including aerial gunner, loadmaster, flight engineer
Revision Sawfly	High compatibility/comfort with flight equipment and communication headgear; lightweight; good field of view; limited dust/debris protection; found compatible with 55P, 56P, FAST helmets by various aircrew positions including aerial gunner, loadmaster, flight engineer
Wiley-X Talon	High compatibility/comfort with flight equipment and communication headgear; lightweight; high degree of fog resistance; limited dust/debris protection; found compatible with 55P, 56P helmets by various aircrew positions including loadmaster, medic, aerial gunner, flight engineer
Oakley SI Ballistic M Frame 2.0	High compatibility/comfort with NVG and visor; good field of view and lens clarity; lightweight; limited dust/debris protection; found compatible with 55P, 56P, FAST helmets by various aircrew positions including loadmaster, flight engineer, aerial gunner, FARP
Revision Exoshield (goggles)	Provides high degree of dust/debris protection; lightweight; good field of view and lens clarity; limited fog resistance; minimum compatibility with helmets; recommended for PJs, Jumpers, and Spec Ops
Revision Bullet Ant (goggles)	Provides high degree of dust/debris protection; minimum compatibility with flight equipment and communication headgear; limited fog resistance; only recommend for aircrew positions conducting tasks or operations in high dust/debris environment

APPENDIX C

Aircrew Ballistic Protective Eyewear (BPE) Study II

BACKGROUND

The Aircrew BPE Study II was conducted in response to the need to provide aircrew with more BPE options. A research protocol was developed to select and test commercial off-the-shelf (COTS) BPE devices in 2012. Assessments of COTS eyewear products facilitated the addition of more BPE options to the FPEL.

METHODS

Compatibility/Human Factors Tests

Human factors tests were conducted by the Natick Soldier Research, Development, and Engineering Center (NSRDEC). Tests included evaluation of the compatibility of eight BPEs with aircrew flight equipment. Tests were conducted using three helmet types (55P, 56P, and the FAST), two oxygen masks (MBU 12P and 20P), and NVG. The human factors evaluation involved wearing each helmet with one or both of the oxygen masks (depending on the helmet type) and NVG, as well as deploying the visor on the 56P helmet. Nine eyewear conditions were tested with each helmet. Additionally, test participants rated each eyewear item on several attributes while wearing only the helmet and the eyewear device. Test participants rated the following items for each test condition:

(a) Ease of adjusting the eyewear for fit
(b) Ease of changing the lenses or prescription insert
(c) Amount of fogging
(d) Restriction of field of view (FOV) (subjective report and objective FOV test)
(e) Amount of lens clarity
(f) Degree of color change due to lens/tint
(g) Ability to see/read text

Tasks (a) and (b) above were rated on a 5-point scale (1=very easy, 2=slightly easy, 3=neither difficult nor easy, 4=slightly difficult, and 5=very difficult). Tasks (c) to (g) were rated on a 5-point scale (0=none, 1=slight, 2=moderate, 3=severe, 4=extreme).

Noise Attenuation Tests

Noise attenuation testing was conducted by the U.S. Army Aeromedical Research Laboratory (USAARL) at zero cost to the Air Force. Testing was conducted to determine the level of acoustic leakage that can be expected when donning eyewear, with or without prescription inserts, while wearing the HGU-55P or HGU-56P flight helmet. Testing was conducted with eight BPE devices, two types of helmets (55P and 56P), and Peltor hearing protection. The Knowles Electronics Manikin for Acoustic Research was set up in a sound chamber, and the Microphone in Real Ear technique was used to evaluate the noise attenuation

provided by each combination of helmets and eyewear. Test setup was the same for the entire measurement series. Tests consisted of the following parameters:

(a) Broadband "pink" noise (flat frequency domain spectrum)
(b) Broadband random noise of at least 85 dB sound pressure level at a frequency spectrum centered from 100 Hz to 10,000 Hz
(c) Overall level measured with the Knowles Electronics Manikin for Acoustic Research: approximately 107 dB(A)

Ballistics Tests

Ballistics tests were conducted at ICS Labs on the BPE devices. Testing was performed to MIL-PRF-31013, Performance Specification-Spectacles, Special Protective Eyewear Cylindrical Systems (SPECS). Testing was conducted in a standard laboratory atmosphere utilizing the following: a pneumatic air gun, propellant (nitrogen), fragment-simulating projectiles (0.15 caliber, 5.8 grain, 4340 steel, hardness 30 ± 2 Rockwell C), Oehler Research precision ballistic chronographs (two sets of screens with 1-foot spacing between start and stop), and a rubber Alderson 50th percentile headform with modified eye sockets and two elliptical 0.0002-inch witness sheets over each eye socket. Samples were mounted on the head form and impacted with a 0.15-caliber projectile at a velocity of 640 to 660 ft/s. Each sample received one impact, normal to the front curve, coincident with either the right or left eye. Left and right impact locations were to the visual centers (a point centered on the horizontal centerline and 32 mm from the vertical centerline). Tests were considered a failure if one or more of the following occurred:

(a) the aluminum foil witness sheet is punctured (if present)
(b) the primary lens is cracked
(c) the prescription lens is cracked (if tested)
(d) one or more fragments or eyewear components, either along the inside of the eyewear or that is needed for proper eyewear retention in the as-worn position, become completely separated from the frame upon impact, including, but not limited to, the primary lens

Luminance transmittance and haze were measured using a BYK-Gardner haze-gard plus. A 5- x 15-mm aperture was mounted to the entrance port of the sphere to isolate the measurement to the abraded area. Abrasion was performed with a 2.5-pound Summers Optical eraser instrument. The eraser insert was connected to a mechanical arm with an adjustable pivot arm so that the instrument could be kept normal to the curved surface of the lens. Samples were abraded 20 cycles (40 strokes). After abrasion, samples were washed with a mild detergent water solution and dried with compressed air. Pass/fail criteria were based on specifications from the MCEP Purchase Description GL-PD 10-12 dated 16 April 2010.

Aircrew Flight Tests

Flight tests were conducted at three test sites: 18th Test Squadron, Hurlburt Field Air Force Base (AFB), FL; 563rd Rescue Group, Davis-Monthan AFB, AZ; and 58th Special Operations Wing, Kirtland AFB, NM. Eight BPEs were tested:

(a) Wiley-X SG-1 (hybrid spectacles/goggles)
(b) Revision Exoshield (goggles)
(c) Wiley-X CQC (goggles)
(d) Revision Sawfly (spectacles)
(e) ESS Suppressor (spectacles)
(f) Oakley SI Ballistic M Frame 2.0 (spectacles)
(g) Wiley-X Talon (spectacles)
(h) Revision Bullet Ant (goggles)

In addition to wearing the BPEs, aircrew also wore NVG, three helmet types (55P, 56P, FAST), two types of oxygen masks (12P, 20P), and heads up display monocle to conduct tests. To test performance of the BPEs, aircrew were required to fly approximately 16 missions (one daytime and one nighttime) and complete a survey on the fit, comfort, flight equipment compatibility, and performance issues.

RESULTS AND RECOMMENDATIONS

Compatibility/Human Factors Tests

Testing was completed April 2012, and NSRDEC submitted a full 73-page report. Findings from each test condition are presented below:

1. Field of view was measured using a Bausch and Lomb Ferree-Rand Projection Perimeter (catalog number 71-77-50). Visual field was tested in eight azimuths/areas—superior, supero-temporal, temporal, inferior-temporal, inferior, inferior-nasal, nasal, and superior-nasal.
    (a) FOV for 55P helmet. Due to the design of the 55P helmet, it offers larger fields of view than other styles of helmets. Each type of eyewear reduced the FOV on at least three of the eight azimuths (superior-temporal, nasal, and superior-nasal). The degradation was greatest in the superior nasal azimuth with the Wiley-X SG-1 and Revision Bullet Ant BPE devices.
    (b) FOV for 56P helmet. The design of the 56P helmet causes a reduction in FOV due to it having a "lip" or overhang at the sides and top. Adding any type of eyewear to the 56P helmet affected the FOV in the nasal and inferior-nasal azimuths. The degradation was largest for the Wiley-X SG-1, Revision Exoshield, and Revision Bullet Ant BPE devices.
    (c) FOV for FAST helmet. The design of the FAST helmet affords the greatest FOV when worn alone. It is also not a full-face style helmet. The addition of any type of eyewear affected FOV in two of the eight azimuths—nasal and superior-temporal. The degradation was largest for the Wiley-X SG-1 and Revision Bullet

Ant BPE devices. In three additional areas (superior, superior-nasal, and inferior-nasal), all BPEs except Revision Exoshield reduced FOV beyond the resolution limit of the perimeter.

2. Human factors data were gathered as each test participant wore the test items and participated in a question-and-answer session. Test participants (TPs) were requested to rate certain attributes and explain their rating or comment.
   (a) Ease of changing lenses. TPs removed and inserted the lenses from each pair of eyewear (except Revision Exoshield, which does not use removable lenses). After they completed the tasks, they rated the ease at which they were able to change the lens. Mean ratings for all of the eyewear fell between "very easy and slightly easy." The Wiley-X Talon was rated as the easiest for changing lenses.
   (b) Ease of adjusting fit. TPs were asked to rate the ease of adjusting the fit and explain the fit characteristics of the eyewear from their perspective. All of the eyewear was judged as easy to adjust, and mean ratings ranged from "very easy" to somewhat below "slightly easy." The Revision Exoshield, ESS Suppressor, and Wiley-X Talon were rated as the easiest for adjusting for fit and don.
   (c) Compatibility. Compatibility was assessed jointly on a yes/no basis by TPs and the evaluators. The 55P helmet was judged to be compatible for 100% of the TPs with the Wiley-X SG-1, Wiley-X CQC, Revision Sawfly, ESS Suppressor, Oakley SI Ballistic M Frame 2.0, and Wiley-X Talon. The 56P helmet was compatible with all of the BPEs, but slight incompatibilities existed with the Wiley-X CQC and Revision Bullet Ant. The FAST helmet was judged to be compatible with all of the BPEs. The 12P oxygen mask when used with the 55P helmet was judged to be compatible with all of the BPEs except the Wiley-X CQC and Revision Bullet Ant. The 20P oxygen mask when worn with any helmet was more often compatible with the BPEs (helmet type had little to no effect upon compatibility). The communication gear/headset contained in the 55P and 56P helmets was judged to be compatible with all of the eyewear. However, it should be noted that earcups will not seal to the ear when used with eyewear because the temples (or goggle strap) break the seal. Also, the temples (or goggle strap) may cause some discomfort. NVG were judged to be compatible with all of the BPEs, allowing for 10 mm of clearance between the eyewear and NVG.
   (d) Lens clarity/distortion. TPs rated the clarity of each lens as they tested it and distortion that they experienced in the line test. The line test method involved TPs looking at a dark line (11.5 inches long by 1 inch wide) held 18 inches away while turning their heads. If the line bent or waved, the BPEs caused distortion. For every eyewear type, the TPs rated the eyewear as having good clarity and zero distortion.
   (e) Color perception. None of the eyewear showed a tendency to alter color perception, as assessed by the color wheels in the Dvorine Pseudoisochromatic Plates test set. All of the TPs' ratings of color change were zero—"none"—for every tested eyewear type (both clear and tinted BPE lens).
   (f) Resistance to fogging. TPs rated the amount of fogging they experienced with the eyewear and were also instructed to point out any fogging that occurred at any time during the evaluation. Occurrences of fogging with the eyewear were

uncommon, and none of the TPs felt that it was a major issue. The fogging caused little to no obstruction of vision when it occurred.

(g) Resistance to scratching. During evaluation, none of the TPs reported any scratches of the lens. The lenses appeared reasonably scratch resistant when donned, doffed, and worn in very light indoor usage over the course of a month. It is unknown how resistant to scratching the devices would be under use in harsher environments, such as outdoors in a desert setting, in aircraft, and in other military uses. Therefore, field use to determine scratch resistance is recommended.

(h) Durability. Data on durability of the eyewear were limited to any issues that arose during laboratory test sessions. None of the devices showed any signs of breakage, wear, or other indications of poor durability before or during testing or upon inspection at the conclusion of data collection. Field testing would be required to determine any durability issues from daily operational use.

3. *Recommendations*: Results from the evaluations show that some of the BPEs performed well for both FOV and compatibility regardless of the helmet worn. Other BPEs performed well with some helmets but not with others. Some performed poorly regardless of the helmet worn. Therefore, recommendations are based on helmet type:

(a) Wiley-X SG-1 is not recommended for use unless FOV is not a concern, since it had the largest decrement in FOV of all of the eyewear types with every helmet. It also had some fit issues.

(b) If goggles are needed, the Revision Exoshield should be worn, as it performed well except for those wearing the 55P helmet. The Revision Exoshield was the least compatible BPE with the 55P helmet due to its fixed curvature and the difficulty in wearing the goggles over the helmet. FOV was also reduced by a larger amount with the 55P than with other helmets. Wearers of the 55P helmet should consider another type of eyewear before using the Revision Exoshield.

(c) The Wiley-X CQC was the least compatible with the 12P and 20P oxygen masks and is not recommended for wear with these two masks.

(d) The Revision Sawfly, ESS Suppressor, and Oakley SI Ballistic M Frame 2.0 are recommended for use with any helmet type.

(e) The Revision Sawfly offered one of the largest fields of view, regardless of helmet type. It was compatible with all of the helmets, although it had minor fit issues for a few TPs. It also was incompatible with the 20P oxygen mask for some TPs.

(f) The ESS Suppressor and the Oakley SI Ballistic M Frame 2.0 performed nearly as well as the Revision Sawfly on FOV and similar or better for compatibility.

(g) The Wiley-X Talon FOV performance was acceptable for the 55P and 56P helmets but poor for the FAST helmet. It was compatible with all three helmets with no fit issues.

(h) The Revision Bullet Ant was incompatible most often with the helmets and oxygen masks. It did not seal in many cases, even when it fit the head and the helmet, and it caused one of the largest decreases in FOV. If goggles are needed, the Revision Exoshield should be considered instead, with the limitations described above in (b).

The data collected by NSRDEC were laboratory based, and as such may not fully represent the capabilities or drawbacks of the tested eyewear in operational settings. It is recommended that aircrew try each BPE type before making a final decision of a particular type. Some types may work better than others based on face shape and size and how a helmet fits an individual. A variety of BPEs should be available as "safe-to-fly" devices to afford the end-user multiple choices.

Noise Attenuation Tests

Testing was completed June 2012. Overall results showed minimum difference in attenuation loss between the flight helmet and the eyewear. Tests conducted with the HGU-55P helmet showed that the Wiley-X SG-1 eyewear with temples and strap had the greatest negative effect on attenuation, which in both cases was just under 2 dB on the higher ear. Tests conducted with the HGU-56P helmet showed that the Wiley-X CQC and the Wiley-X Talon with long temples had the greatest negative effect on attenuation, which in both cases was just over 1 dB on the higher ear. In most cases with both flight helmets, eyewear inserts introduced additional small attenuation loss.

Recommendations: Based on these results, the following are recommended:

- When wearing the HGU-55P helmet, it would probably be best to select eyewear other than the Wiley-X SG-1 unless double protection is worn.
- The effect on actual noise exposure is dependent on the exposure time and noise environment, but the 2-dB increase in level due to the Wiley-X SG-1 eyewear could reduce allowable exposure time by 25%.
- Temple thickness of protective eyewear should not exceed 4 mm; however, temple comfort might play a role on user acceptance.

Ballistics Tests

Testing was completed June 2012; earlier ballistic tests were also conducted by another organization (PEO Soldier) on the BPE Study II devices. Findings showed that all of the BPEs meet the V0 MCEP ballistic requirements. However, the MCEP abrasion requirement was not met on one of the BPEs (Wiley-X CQC).

Recommendations: It is recommended that ballistic tests be conducted on randomly selected BPE samples and tested in the as-received condition. This initiative can be facilitated by:

- establishment of a Flight Protective Eyewear Review Board Charter chaired by the U.S. Air Force/SG Aerospace Ophthalmology Consultant and consisting of board members with expertise in medical, engineering, and product quality (end-users)
- participating in joint military research studies with organizations such as USAARL

Flight Tests

Testing was completed September 2012. In total, 426 surveys were received. On the surveys, aircrew were asked to rate how each BPE performed on a scale of 1 (worst performance) to 5 (best performance). The Revision Bullet Ant was rated highest on debris

protection. The Wiley-X CQC was rated highest in Rx insert security, BUT inserts aren't authorized for the Wiley-X CQC, so these data are erroneous (basically, it didn't rate higher in any category in comparison to the other BPEs). The ESS Suppressor was rated highest in adjustment ease, eyewear weight, hot spot resistance, and fog resistance. The Revision Exoshield was rated highest in don mask and smoke mask compatibility. The Oakley SI Ballistic M-Frame 2.0 was rated highest in appearance, task comfort, FOV, lens clarity, NVG compatibility, and device durability. The Revision Sawfly was rated highest in lens change ease, Rx insertion, visor compatibility, don mask compatibility, and other equipment compatibility. The Wiley-X SG-1 was not rated highest in any category. The Wiley-X Talon was rated highest in insert comfort, helmet compatibility, oxygen mask compatibility, and communication gear compatibility. Below are graphs that show assessment of the BPEs in 23 performance factors. The 23 factors are divided evenly among three graphs for ease of reading (Figures C-1, C-2, and C-3).

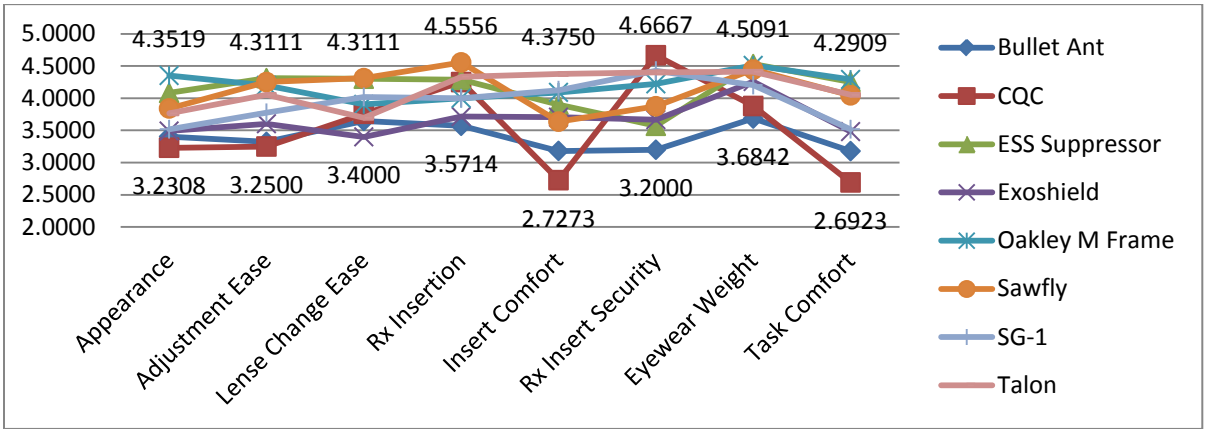

Figure C-1. BPE Performance on First Eight Factors Rated by Aircrew

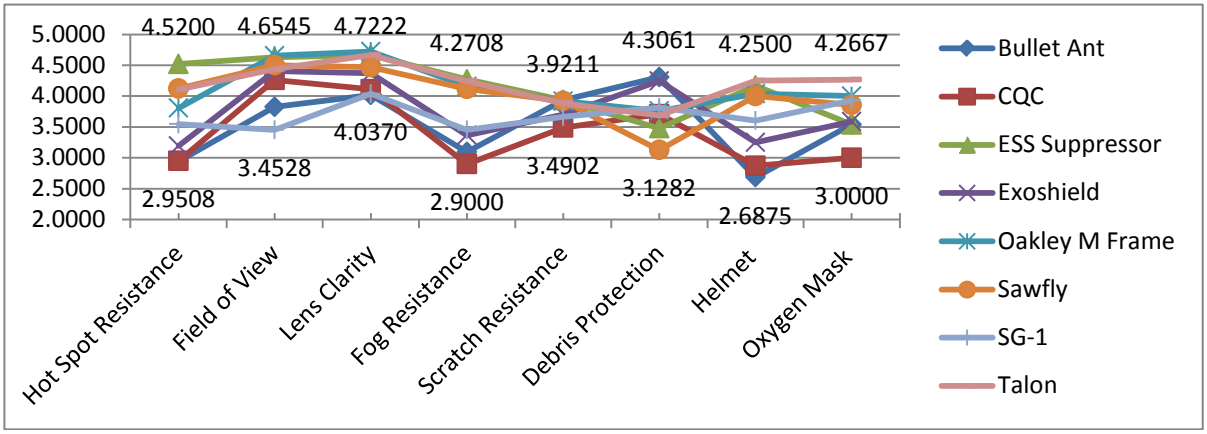

Figure C-2. BPE Performance on Second Eight Factors Rated by Aircrew

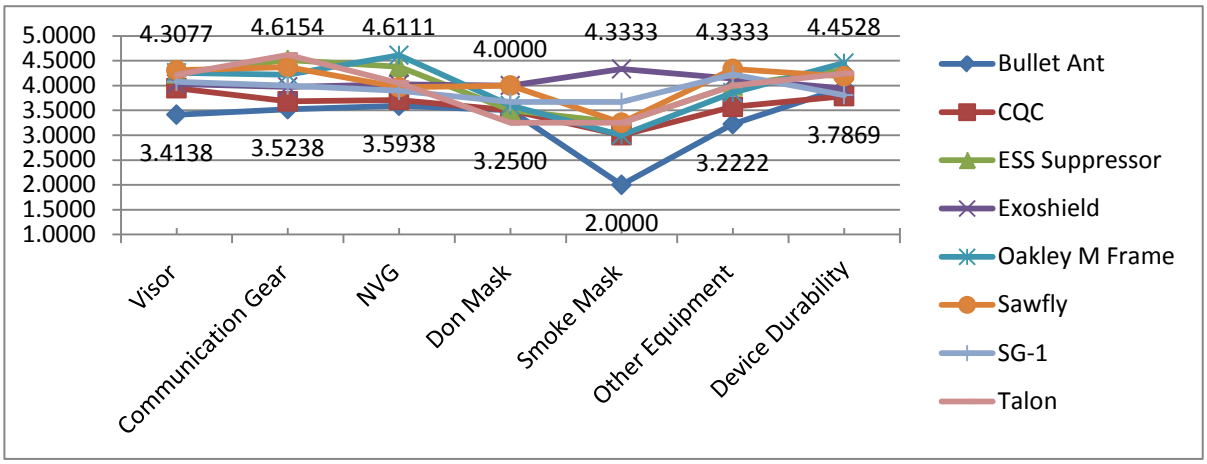

Figure C-3. BPE Performance on Last Seven Factors Rated by Aircrew

Scores in all of the performance areas were averaged to obtain "Overall Performance" results. One of the aims of this study was to obtain two "Overall Performance" results—daytime and nighttime missions. However, many aircrew used only one survey to evaluate BPE performance during day and nighttime missions; thus, a comparison of day and nighttime performance cannot be parsed from the data. For overall performance, the ESS Suppressor was rated the highest, followed by the Oakley SI Ballistic M-Frame 2.0, the Wiley-X Talon, and the Revision Sawfly. The Wiley-X CQC was rated the lowest, followed by the Revision Bullet Ant and Wiley-X SG-1. Figure C-4 depicts BPE overall performance.

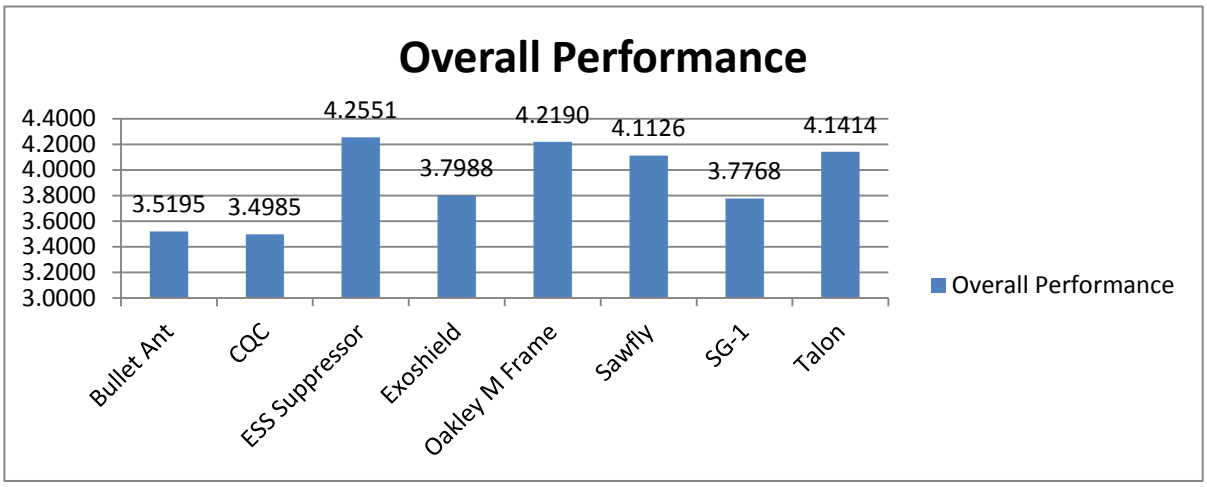

Figure C-4. BPE Overall Performance Based on Average Scores During Day and Nighttime Missions

On the survey, aircrew were asked to prioritize seven key performance factors in terms of being most important to least important on BPE devices. Comfort was ranked as the most important factor, followed by FOV, dust/debris protection, hot spots, fog resistance, scratch resistance, and the look. Figure C-5 depicts the ranking of performance factors.

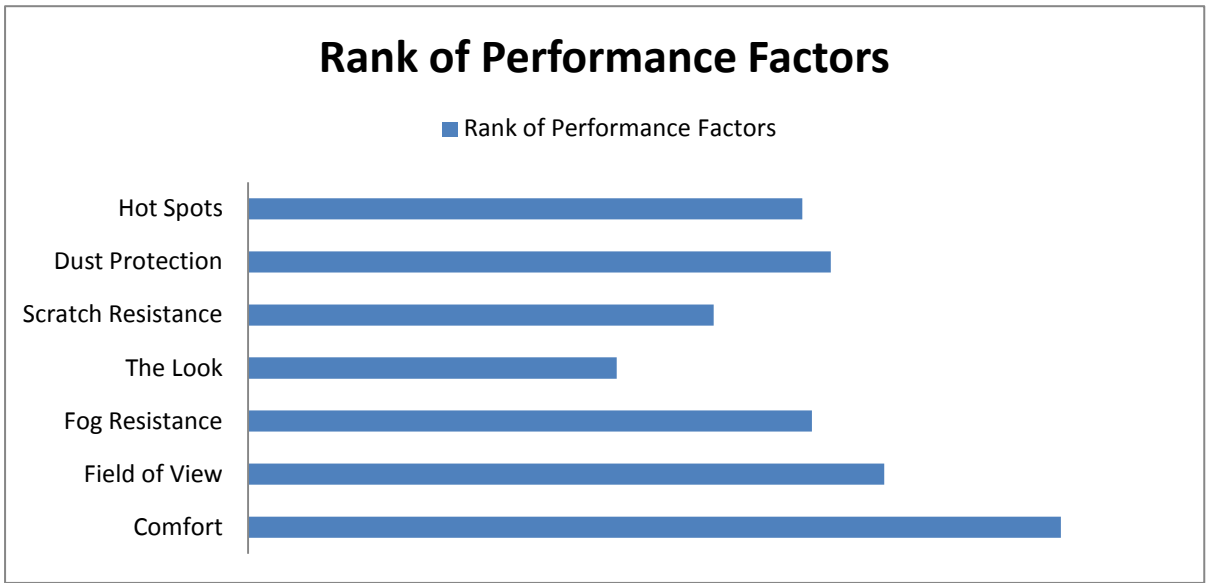

Figure C-5. Key Performance Factors Ranked by Importance in BPE Design

Analyses were conducted to determine how each BPE performed in four key areas that were prioritzed by aircrew in importance to the design of eyewear devices. The four areas were task comfort, hot spot resistance, FOV, and debris protection. Results showed that the Oakley SI Ballistic M-Frame 2.0 was rated the highest in comfort and FOV, the ESS Suppressor was rated highest in hot spot resistance, and the Revision Bullet Ant was rated highest for providing dust/debris protection. Figure C-6 depicts the evaluation of the BPEs in four key performance areas.

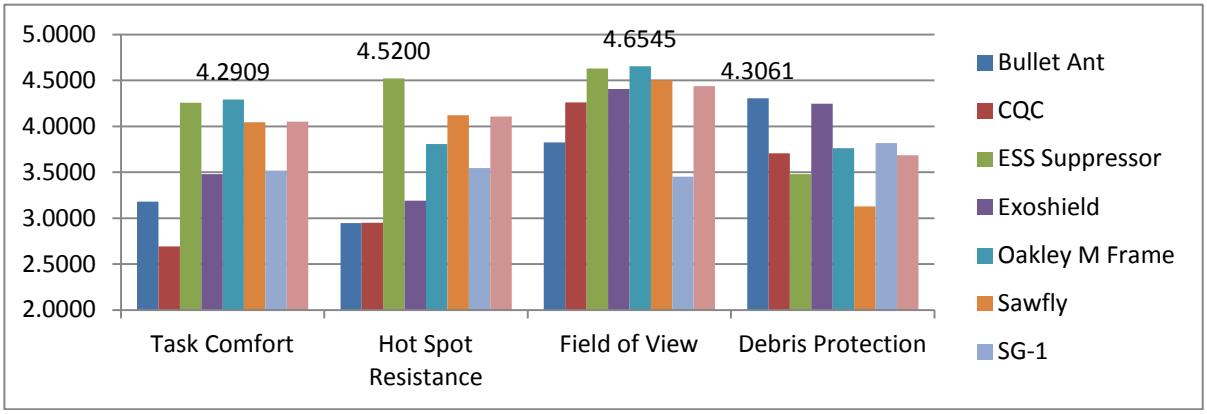

Figure C-6. Evaluation of Eight BPE Devices in Four Key Performance Areas Ranked by Aircrew

Recommendations: The Aircrew BPE Study II involved collecting data in an operational setting at three test sites over a 1-year period. Based on the BPEs' performance in the 23 survey categories, the following are recommended:

- The ESS Suppressor, Oakley SI Ballistic M-Frame 2.0, Wiley-X Talon, Revision Sawfly, Revision Exoshield, and Revision Bullet Ant should be included on the FPEL.

- Remove the Wiley-X CQC (goggles) from the FPEL due to issues (low performance) on certain survey factors—task comfort, hot spot resistance, and flight equipment compatibility, as well as its performance on NSRDEC and noise attenuation evaluations.
- Future BPE studies on COTS devices are needed to ensure aircrew are equipped with devices that provide the best eye protection.
- Research is needed to discover materials that can provide high levels of both laser and ballistic eye protection in one device.

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LIST OF ABBREVIATIONS AND ACRONYMS

AFB	Air Force Base
ANSI	American National Standards Institute
BPE	ballistic protective eyewear
COTS	commercial off-the-shelf
FOV	field of view
FPE	flight protective eyewear
FPEL	Flight Protective Eyewear List
MCEP	Military Combat Eye Protection
NSRDEC	Natick Soldier Research, Development, and Engineering Center
NVG	night vision goggles
UPLC	Universal Prescription Lens Carrier
USAARL	U.S. Army Aeromedical Research Laboratory
UV	ultraviolet

GLOSSARY

Bevel	The crown on a lens that allows it to match the inside groove or bezel of an eyewire.
Bezel	The groove in the eyewire that anchors the lens element within the frame.
Eyewire	That part of a spectacle frame that wraps around and secures the lens element.
Eyewire tube	The section screwed together when securing a lens in an eyewire.
FPE	Flight protective eyewear that is worn by aircrew members. Spectacles and goggles that protect the eyes from dust, flyng debris, and ballistic fragmentation.
Index of refraction	The ratio of the group velocity of light of a given wavelength in air to that in a given medium. It defines the ability of a material to bend or refract light of a given wavelength. The higher the index, the greater the bending or refracting power. Reference wavelength used is the helium d-line at 587.56 nm.
Temple	The extended earpiece of a spectacle frame that is mounted to the spectacle front eyewire usually with a three-, five-, or seven-barrel hinge. Also called “sidepiece” or “leg.”
UPLC	Universal Prescription Lens Carrier is inserted into the FPE device to provide vision correction for aircrew who require a prescription to see clearly.